US010588177B2

(12) **United States Patent**
Spalding, Jr. et al.

(10) **Patent No.: US 10,588,177 B2**
(45) **Date of Patent: Mar. 10, 2020**

(54) **APPARATUS FOR CURING COMPOSITE MATERIALS AND METHOD OF USE THEREOF**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 100 days.

(21) Appl. No.: **15/727,804**

(22) Filed: **Oct. 9, 2017**

(65) **Prior Publication Data**

US 2018/0035489 A1 Feb. 1, 2018

Related U.S. Application Data

(62) Division of application No. 14/512,329, filed on Oct. 10, 2014, now Pat. No. 9,788,366.

(51) **Int. Cl.**
H05B 3/06 (2006.01)
H05B 3/04 (2006.01)
H05B 3/34 (2006.01)
H01R 13/52 (2006.01)

(52) **U.S. Cl.**
CPC ***H05B 3/04*** (2013.01); ***H05B 3/06*** (2013.01); ***H05B 3/34*** (2013.01); *H01R 13/5219* (2013.01); *H05B 2203/003* (2013.01)

(58) **Field of Classification Search**
CPC H01R 13/52; H01R 13/5202; H01R 13/5219; H01R 13/5221; B29C 2043/3655; B64F 5/0081
USPC 439/271–277, 587–589
See application file for complete search history.

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(57) **ABSTRACT**

A method of supplying electricity to an electrical component inside a vacuum chamber may include positioning an electrical component inside a vacuum chamber, the electrical component having a first electrical connector portion. A second electrical connector portion may then be connected to the first electrical portion through a hole in a flexible wall of the vacuum chamber, the second electrical connector portion being electrically connected to circuitry disposed outside the vacuum chamber. The connecting step may include hermetically clamping the flexible wall of the vacuum chamber between the first and second electrical connector portions.

20 Claims, 5 Drawing Sheets

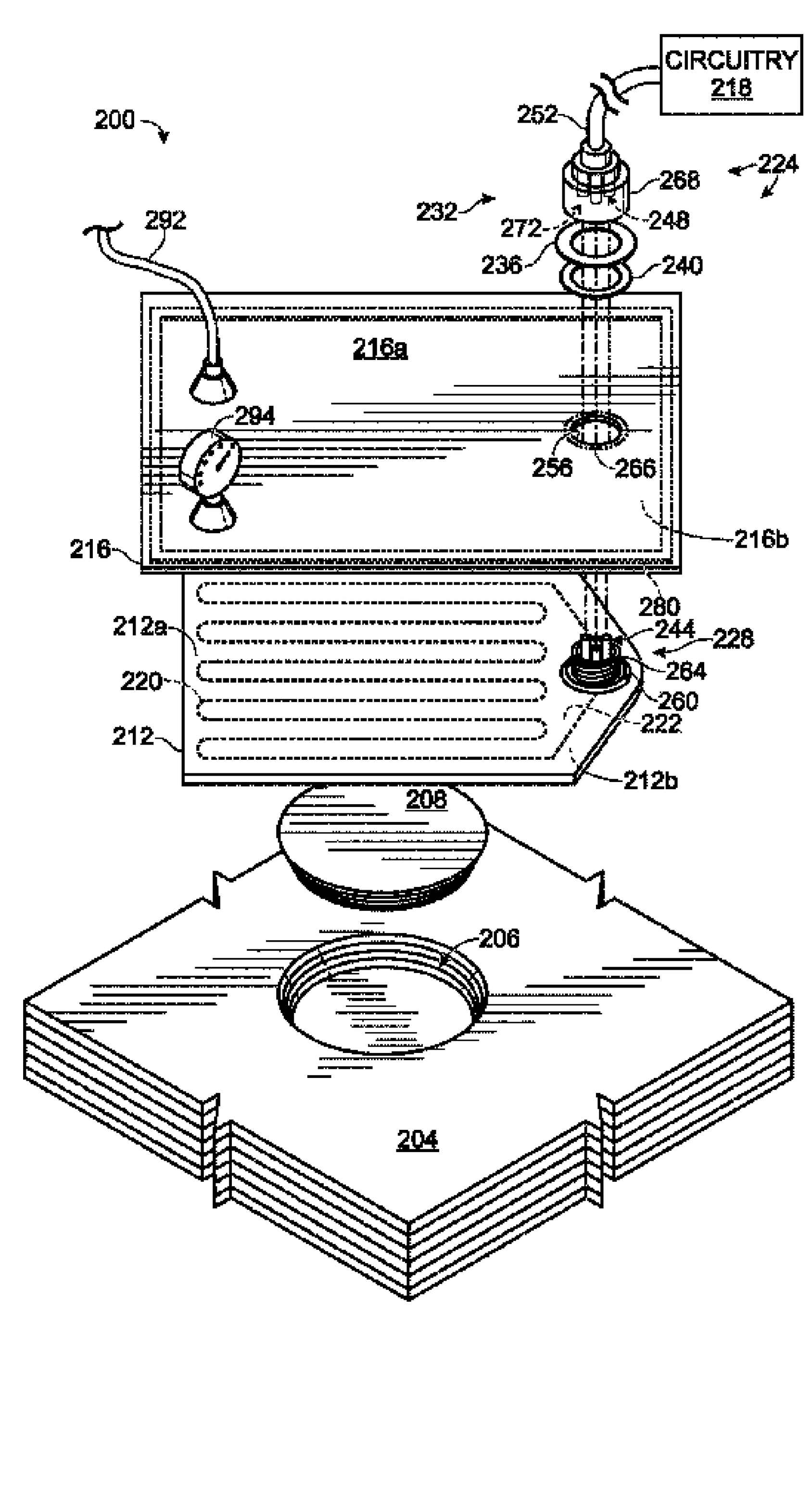

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Fig. 1

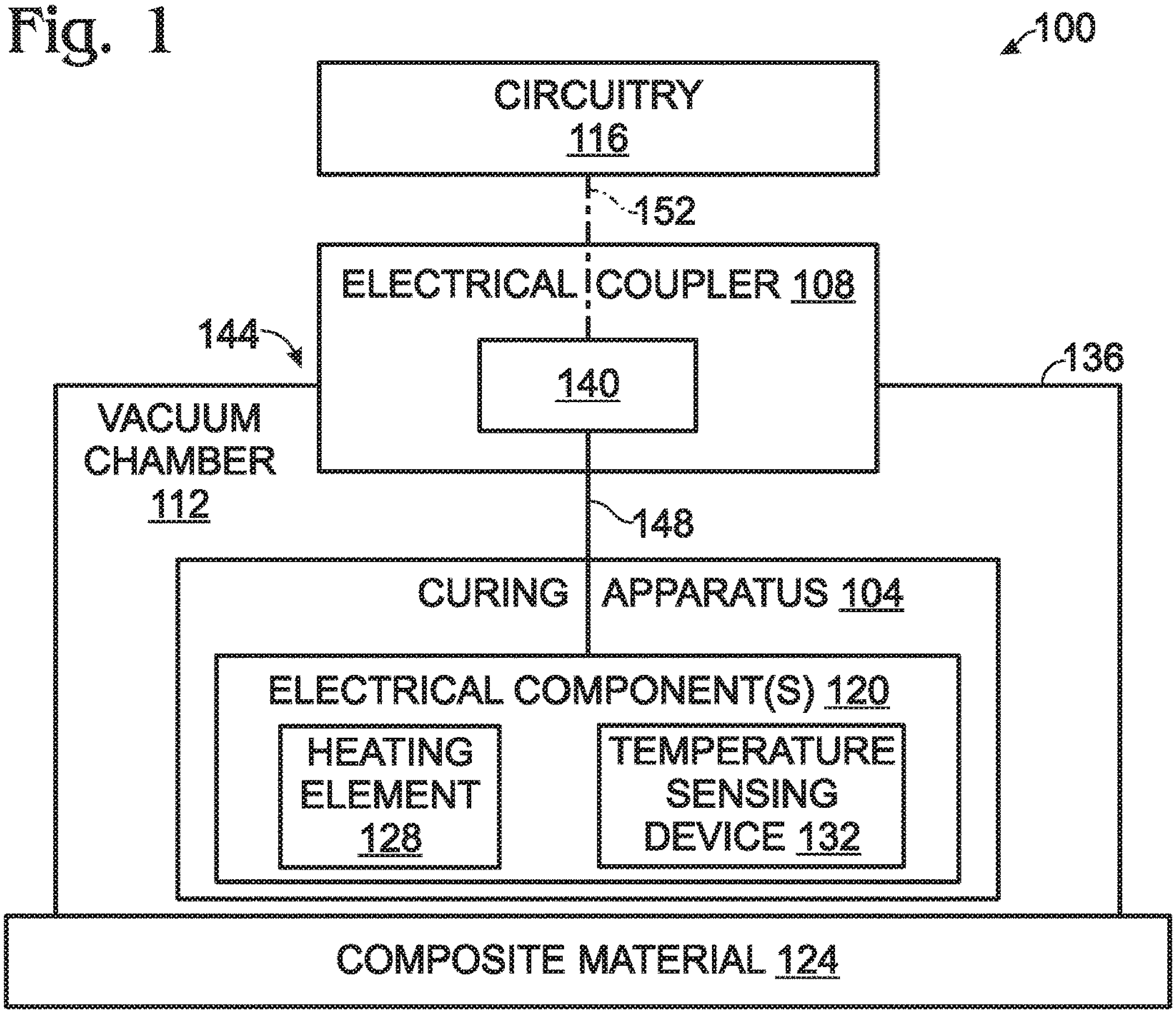

100
CIRCUITRY
116
152
ELECTRICAL COUPLER 108
144
136
140
VACUUM
CHAMBER
112
148
CURING APPARATUS 104
ELECTRICAL COMPONENT(S) 120
HEATING
ELEMENT
128
TEMPERATURE
SENSING
DEVICE 132
COMPOSITE MATERIAL 124

Fig. 4

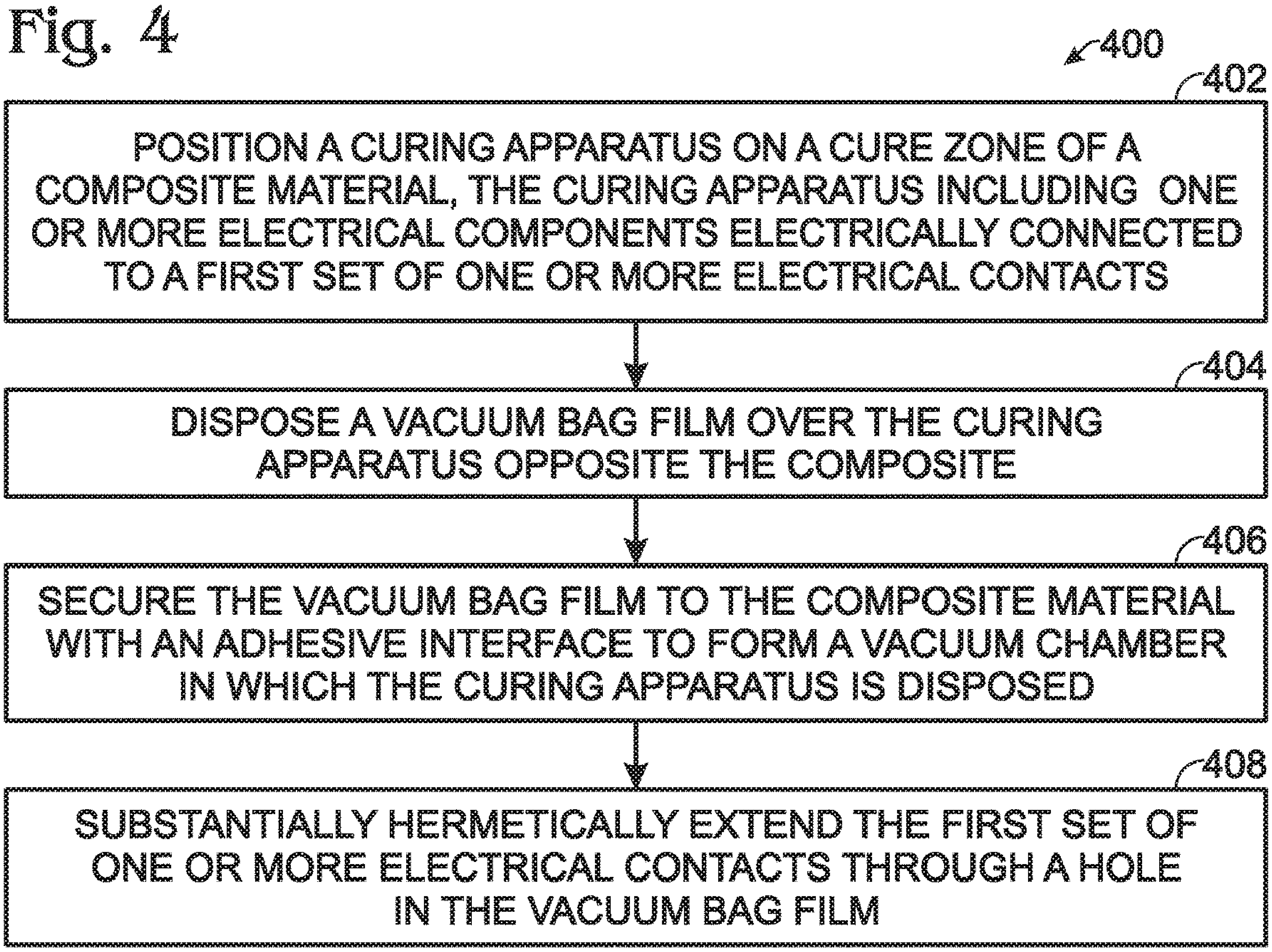
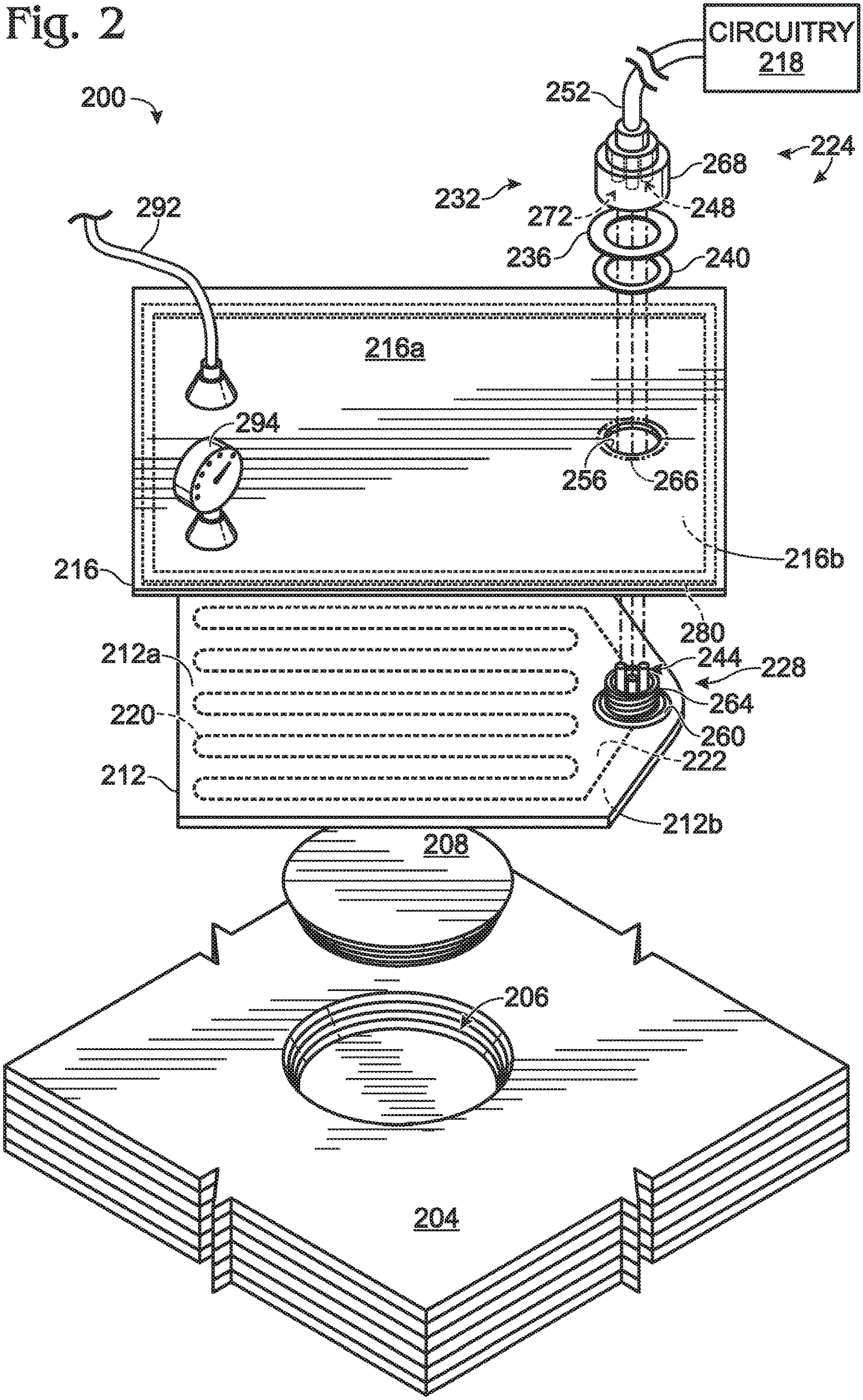

400
402
POSITION A CURING APPARATUS ON A CURE ZONE OF A COMPOSITE MATERIAL, THE CURING APPARATUS INCLUDING ONE OR MORE ELECTRICAL COMPONENTS ELECTRICALLY CONNECTED TO A FIRST SET OF ONE OR MORE ELECTRICAL CONTACTS
404
DISPOSE A VACUUM BAG FILM OVER THE CURING APPARATUS OPPOSITE THE COMPOSITE
406
SECURE THE VACUUM BAG FILM TO THE COMPOSITE MATERIAL WITH AN ADHESIVE INTERFACE TO FORM A VACUUM CHAMBER IN WHICH THE CURING APPARATUS IS DISPOSED
408
SUBSTANTIALLY HERMETICALLY EXTEND THE FIRST SET OF ONE OR MORE ELECTRICAL CONTACTS THROUGH A HOLE IN THE VACUUM BAG FILM

Fig. 2



CIRCUITRY
218
200
252
224
268
232
272
248
292
236
240
216a
294
256
266
216
216b
280
212a
244
228
264
220
260
222
212
212b
208
206
204

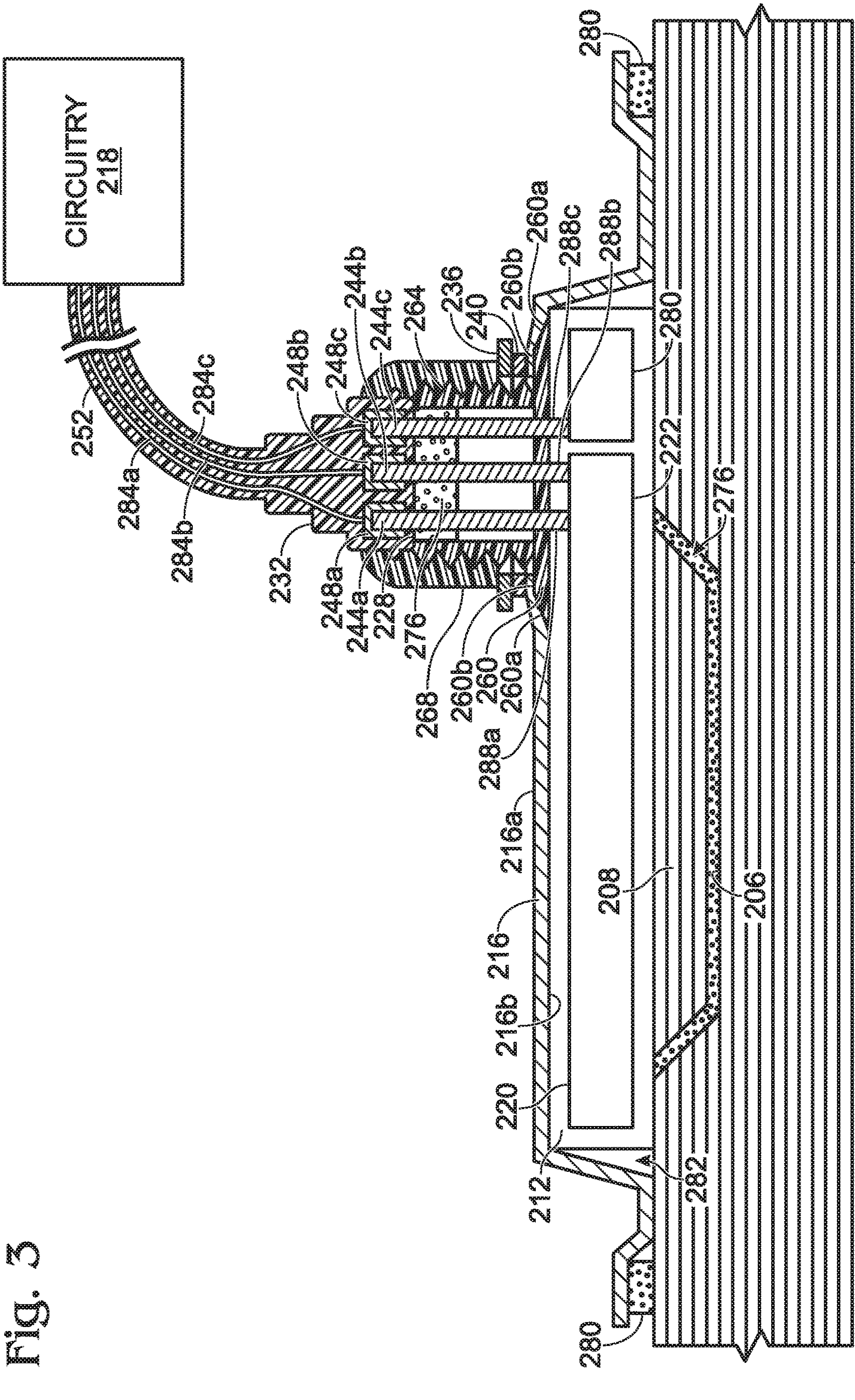

CIRCUITRY
218
252
284a
284b
284c
232
248a
248b
248c
244a
244b
244c
228
276
264
268
236
240
260
260a
260b
288a
288b
288c
280
222
216
216a
216b
220
212
282
208
206
204

Fig. 3

Fig. 5

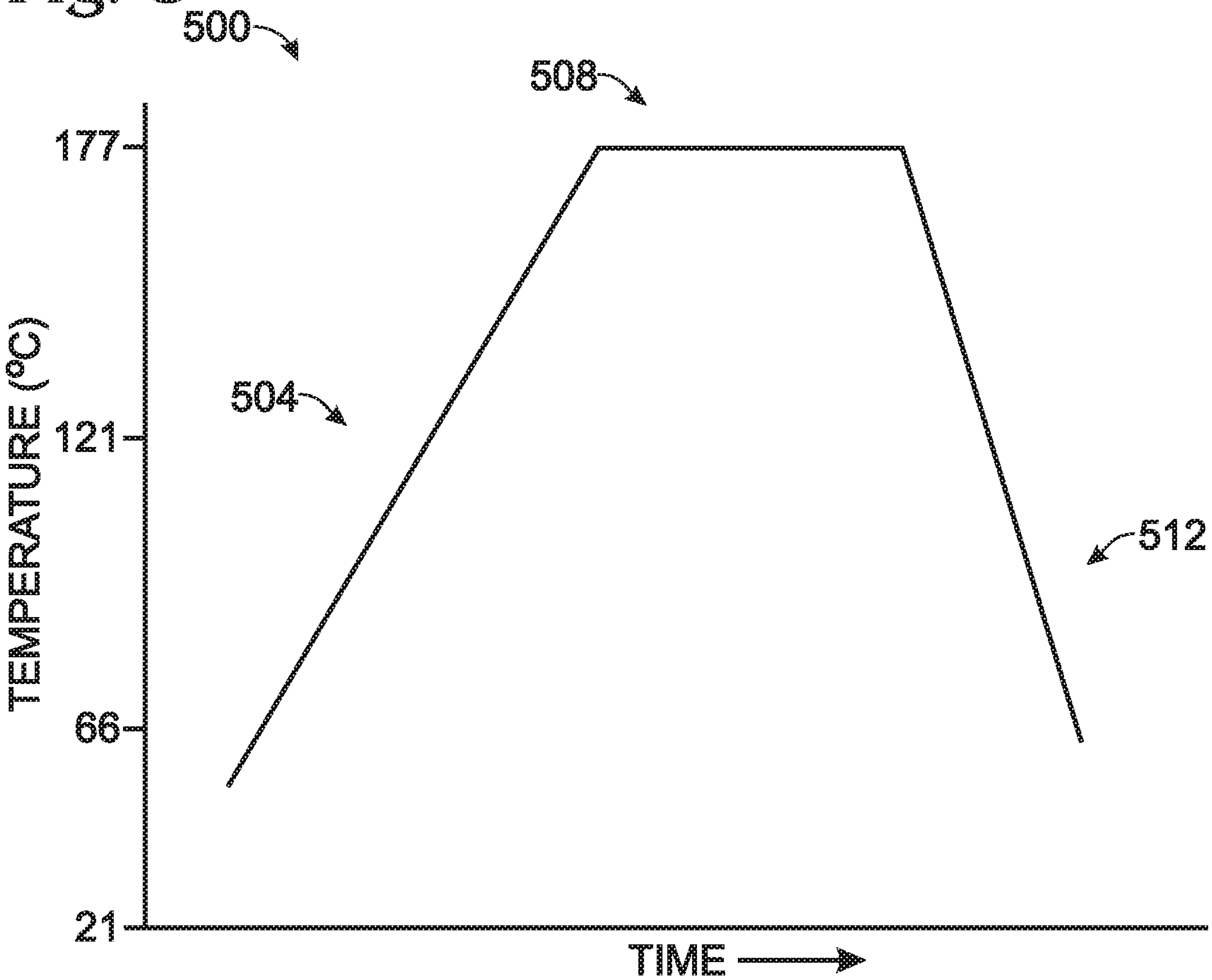
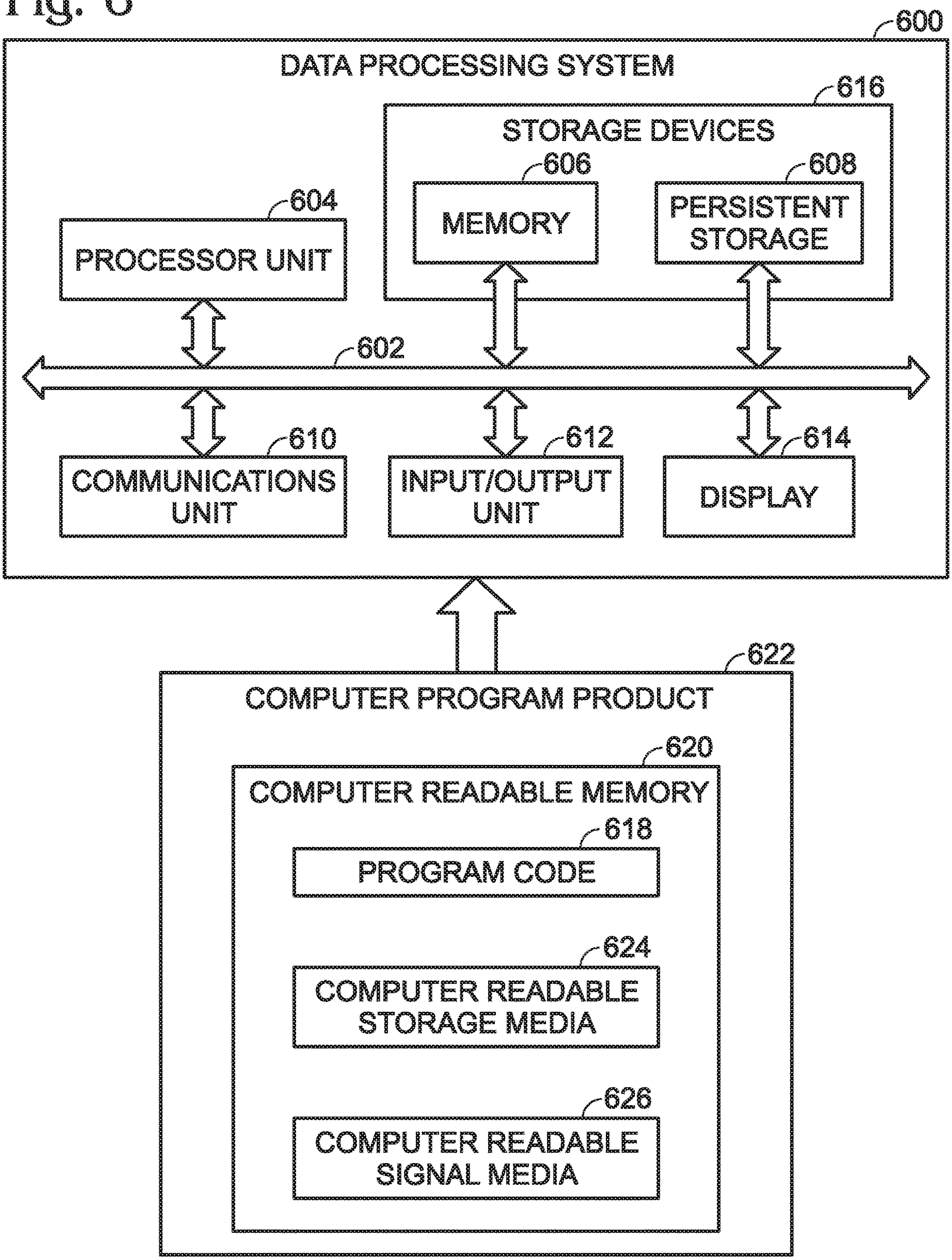


Fig. 6


600
DATA PROCESSING SYSTEM
616
STORAGE DEVICES
606
MEMORY
608
PERSISTENT STORAGE
604
PROCESSOR UNIT
602
610
COMMUNICATIONS UNIT
612
INPUT/OUTPUT UNIT
614
DISPLAY
622
COMPUTER PROGRAM PRODUCT
620
COMPUTER READABLE MEMORY
618
PROGRAM CODE
624
COMPUTER READABLE STORAGE MEDIA
626
COMPUTER READABLE SIGNAL MEDIA

APPARATUS FOR CURING COMPOSITE MATERIALS AND METHOD OF USE THEREOF

CROSS-REFERENCES TO RELATED APPLICATIONS

This application is a divisional application of U.S. patent application Ser. No. 14/512,329, filed Oct. 10, 2014. The complete disclosure of the above-identified patent application is hereby incorporated by reference for all purposes.

FIELD

This disclosure relates to apparatuses and methods associated with curing composite materials. More specifically, the disclosed embodiments relate to systems and methods for electrically interconnecting a composite material curing apparatus disposed inside a vacuum chamber with circuitry disposed outside the vacuum chamber.

INTRODUCTION

Composite materials are typically made from two or more constituent materials with significantly different physical or chemical properties. Typically, the constituent materials include a matrix (or bond) material, such as resin (e.g., thermoset epoxy), and a reinforcement material, such as a plurality of fibers (e.g., a woven layer of carbon fibers). When combined, the constituent materials typically produce a composite material with characteristics different from the individual constituent materials even though the constituent materials generally remain separate and distinct within the finished structure of the composite material. Carbon-fiber-reinforced polymer is an example of such a composite material.

Composite materials may be preferred for many reasons. For example, composite materials may be stronger and/or lighter than traditional materials. As a result, composite materials are generally used to construct various objects such as vehicles (e.g., airplanes, automobiles, boats, bicycles, and/or components thereof), and non-vehicle structures (e.g., buildings, bridges, swimming pool panels, shower stalls, bathtubs, storage tanks, and/or components thereof).

Occasionally, these composite materials may become damaged, in which case it may be preferable to repair the damaged composite material rather than replace it entirely. Such composite repairs are typically performed without the use of an oven or an autoclave to provide heat. In these instances, an alternative heat source, such as a heater mat (e.g., including electrical resistance wires encapsulated in silicon rubber), may be used to raise the temperature of a composite repair material to a cure temperature.

Generally, the heater mat and the composite repair material are compacted toward the damaged composite material through atmospheric pressure applied via a vacuum bag film, which is sealed to the damaged composite material by adhesive tape to form a vacuum chamber. Pre-existing apparatuses and methods involve routing power leads for the heater mat and associated sensor wires out of the vacuum chamber between an interface of the vacuum bag film and the composite material, and sealing the interface with several layers of vacuum sealant tape. However, these pre-existing apparatuses and methods may sometimes create leaks in the vacuum chamber, damage various components during a debagging process, and require significant lay-up time.

SUMMARY

Disclosed herein are various examples of apparatuses and methods, which may decrease vacuum chamber leaks, reduce damage to various components, and/or reduce lay-up times.

In one example, an apparatus may include a curing apparatus and an electrical coupler. The curing apparatus may include one or more electrical components related to curing a composite material inside a vacuum chamber at least partially defined by a flexible wall. The electrical coupler may be connected to the curing apparatus. The coupler may include a first set of one or more electrical contacts electrically connected to the one or more electrical components of the curing apparatus inside the vacuum chamber. The coupler may be configured to hermetically extend through a hole in the flexible wall. Such extension may dispose the first set of one or more electrical contacts in a space outside of the vacuum chamber for electrical interconnection of the one or more electrical components of the curing apparatus inside the vacuum chamber with circuitry disposed in the space outside of the vacuum chamber.

In another example, an apparatus may include a heater mat and an electrical coupler. The heater mat may include one or more electrical components for applying thermal energy to a composite material inside a vacuum chamber. The vacuum chamber may be at least partially defined by a flexible wall. The flexible wall may be configured to apply a pressing force against the composite material via the heater mat when the vacuum chamber is substantially evacuated and as the application of the thermal energy at least partially cures the composite material to a substantially cured state. The electrical coupler may include male and female connector portions. One of the male and female connector portions may be connected to the heater mat. The connector portion that is connected to the heater mat may include a first set of one or more electrical contacts electrically connected to the one or more electrical components of the heater mat. The other of the connector portions may include a second set of one or more electrical contacts configured for electrical connection to circuitry disposed outside of the vacuum chamber. The electrical coupler may be configured to extend through and hermetically seal a hole in the flexible wall, and to electrically interconnect the first and second sets of one or more electrical contacts when the male and female connector portions are mated for electrical interconnection of the one or more electrical components of the heater mat disposed inside the vacuum chamber with the circuitry disposed outside of the vacuum chamber.

In another example, a method may include positioning a curing apparatus on a cure zone of a composite material. The curing apparatus may include one or more electrical components electrically connected to a first set of one or more electrical contacts. The method may further include disposing a vacuum bag film over the curing apparatus opposite the composite material. The method may further include securing the vacuum bag film to the composite material with an adhesive interface to form a vacuum chamber in which the curing apparatus is disposed. The method may further include hermetically extending the first set of one or more electrical contacts through a hole in the vacuum bag film.

The present disclosure provides various apparatuses and methods for hermetically passing electrical connections

through an opening (or hole) in a flexible wall of a vacuum chamber. In some embodiments, the first connector portion may be mounted on the curing apparatus (e.g., on a heater mat). In some embodiments, mating the first and second connector portions may both electrically interconnect the respective first and second sets of one or more electrical contacts and may hermetically seal the hole in the flexible wall through which the coupler extends. In some embodiments, an interior of the first connector portion may be hermetically sealed with a potting material from which the first set of one or more electrical contacts may protrude.

The features, functions, and advantages may be achieved independently in various embodiments of the present disclosure, or may be combined in yet other embodiments, further details of which can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is general block diagram schematically illustrating a system including an electrical coupler configured for electrically interconnecting a curing apparatus disposed inside a vacuum chamber with circuitry disposed outside the vacuum chamber.

FIG. **2** is a semi-schematic partially exploded perspective view of a system including a composite material surface including a rework area, a composite material patch, a flexible vacuum bag film, an adhesive interface, circuitry, and an embodiment of the electrical coupler and curing apparatus of FIG. **1**, with the electrical coupler shown here as including mateable first and second connector portions, and the curing apparatus as including a heater mat to which the first connector portion is mounted.

FIG. **3** is semi-schematic partial cross-sectional view of a lay-up of the system of FIG. **2** including the film secured to the composite material surface by the adhesive interface to form a vacuum chamber in which the heater mat is disposed, the first and second connector portions in a mated position to electrically interconnect respective first and second sets of one or more electrical contacts and to seal a hole in the vacuum bag film through which the electrical coupler extends, and the vacuum chamber evacuated so that the film applies a pressing force against the composite material and the patch via the heater mat.

FIG. **4** is a flowchart depicting a method.

FIG. **5** is a chart illustrating an exemplary cure cycle.

FIG. **6** is a schematic diagram of various components of an illustrative data processing system.

DESCRIPTION

Overview

Various embodiments of systems, apparatuses, and methods are described below and illustrated in the associated drawings. Unless otherwise specified, systems, apparatuses, and/or methods and/or their various components and/or steps may, but are not required to, contain at least one of the structure, components, functionality, and/or variations described, illustrated, and/or incorporated herein. Furthermore, the structures, components, functionalities, and/or variations described, illustrated, and/or incorporated herein in connection with the present teachings may, but are not required to, be included in other similar systems, apparatuses, and/or methods. The following description of various embodiments is merely exemplary in nature and is in no way intended to limit the disclosure, its application, or uses. Additionally, the advantages provided by the embodiments, as described below, are illustrative in nature and not all embodiments provide the same advantages or the same degree of advantages.

Generally, success of a composite repair is related to the vacuum chamber formed by the vacuum bag being substantially leak free. In particular, if the vacuum chamber has significant leaks, then the vacuum bag may not apply a sufficient compacting or pressing force on a composite material patch toward a repair area of an existing composite material (or other suitable bond interface). For example, a large portion of composite repair processes require that the vacuum chamber formed by the vacuum bag be leak tested prior to starting a cure cycle. Typically, the maximum allowable leak rate is 5 inches of mercury (5 inHg, or 127 mmHg) in a five minute interval. Further, some repair processes are more restrictive and only allow a leak rate of 2 inHg (or 51 mmHg).

Pre-existing methods of connecting a heater mat (or heat blanket) to a power supply involve routing power leads of the heater mat out of the vacuum chamber through an interface of the vacuum bag and the composite material, and applying several layers of vacuum sealant tape to the power leads at the interface in an attempt to seal the vacuum chamber, as described above. However, these pre-existing methods typically pose various problems, such as vacuum leaks, poor durability, and complicated lay-ups or configurations resulting in significant bagging and debagging process times, as mentioned above and described below in more detail.

In particular, space between a power lead insulating sleeve and conductor wire (e.g., disposed in the insulating sleeve) typically creates a leak path for air to enter the vacuum chamber in pre-existing methods and apparatuses. For example, air typically enters the insulating sleeve at a termination of the insulating sleeve associated with a plug making the connection to the power supply. This air then travels inside the insulating sleeve into the vacuum chamber. Thus, it is not unusual for pre-existing new and unused heat blankets to cause vacuum leaks in excess of 127 mmHg in five minutes through their power leads. Such a high leak rate typically renders a heat blanket unsuitable for performing a composite repair inside a vacuum chamber with pre-existing methods.

Further, power leads of pre-existing heat blankets are often damaged or cut during debagging operations (or processes) associated with pre-existing apparatuses and methods. For example, the vacuum sealant tape used to "seal" the interface between the vacuum bag, power leads, and composite material is typically extremely sticky and strong, and extracting the heat blanket power leads from such tape often requires significant pulling, tugging, and cutting. Such pulling, tugging, and/or cutting often causes breakage of the conductor wire of the power lead, damage to the insulating sleeve of the power lead, and/or increased vacuum leaks (e.g., as such damage to the power leads may increase air flow into the vacuum chamber if used in a subsequent repair process).

Moreover, as heat blanket technology becomes more sophisticated, the number of wires for powering and controlling the blanket often increases. For example, a multi-zone heat blanket and control system may include an array of 32 heat zones incorporated into a single blanket, with each individual zone having two power leads and an associated control thermocouple. Such a system may include a total of 96 or more wires to be routed under the vacuum bag and through the vacuum sealant tape, making for complicated and time consuming bagging and debagging operations.

However, embodiments of the present disclosure may overcome and/or avoid one or more of the problems described above. For example, embodiments disclosed herein may connect electrical components (e.g., heating elements and/or sensing elements) of or associated with a heater mat to circuitry (e.g., a power supply and/or control equipment) outside of the vacuum chamber in a robust, time efficient, and/or leak free manner. In one embodiment, an electrical coupler including an inner connector and an outer connector may be incorporated into (or at least partially integral with) a heater mat. For example, the inner connector may be integral with (e.g., mounted on) the heater mat. Electrical contacts may be disposed in an interior of the inner connector and electrically connected to one or more of the electrical components of the heater mat. The inner connector may exit the vacuum chamber through an aperture (or opening, or hole) in the vacuum bag. A rubber gasket (or washer, or other suitably resilient member), and a rigid compression washer (or other suitably rigid member) may be serially placed over (e.g., around) the inner connector that protrudes through the aperture in the vacuum bag. The outer connector, which may include electrical contacts configured for electrical connection to the circuitry, may be threaded onto (or otherwise coupled to) the inner connector and tightened. Tightening the outer connector onto the inner connector may provide a reliable and robust vacuum tight seal by sandwiching the vacuum bag between the compressed rubber washer and a base flange of the inner connector. Further, such mating of the inner and outer connectors may electrically interconnect the electrical contacts of the inner connector with the corresponding electrical contacts of the outer connector for operation and/or monitoring of the electrical components of the heater mat disposed inside the vacuum chamber by the circuitry disposed outside of the vacuum chamber. Moreover, the interior of the inner connector may be sealed with a potting compound, or other suitable material (or apparatus, device, structure, and/or mechanism) for preventing a vacuum leak via the interior of the inner connector.

Such a configuration may significantly reduce vacuum leaks, particularly as compared to pre-existing configurations and methods. Further, a durability of such a configuration may be significantly improved as compared to pre-existing configurations. In particular, in such a configuration, removing the heater mat from the vacuum bag (e.g., in a debagging process) may merely involve unscrewing the outer connector from the inner connector and decoupling the respective electrical contacts from one another. Moreover, a convenience (or efficiency) of connecting such a configuration (e.g., in a bagging process) may be improved. For example, since the electrical coupler may be integrated into the heater mat, may include multiple electrical contacts for multiple electrical components inside the vacuum chamber, and may be configured to hermetically extend through and seal a hole in the vacuum bag, routing a plurality of wires under the vacuum bag and through the interface of the vacuum bag and the composite material with sealant tape may be avoided.

EXAMPLES, COMPONENTS, AND ALTERNATIVES

The following examples describe selected aspects of exemplary apparatuses as well as related systems and/or methods. These examples are intended for illustration and should not be interpreted as limiting the entire scope of the present disclosure. Each example may include one or more distinct inventions, and/or contextual or related information, function, and/or structure.

Example 1

This example describes an illustrative system **100** including a curing apparatus **104**, an electrical coupler **108**, a vacuum (or air-tight) chamber **112**, and circuitry **116**; see FIG. **1**.

In this example, curing apparatus **104** may include one or more electrical components **120**. Electrical components **120** may be related to curing a composite material **124** inside vacuum chamber **112**. For example, electrical components **120** may include a heating element (or device) **128** and a temperature sensing device (or sensing element) **132**. Heating element **128** may be included in a heater mat. Temperature sensing device **132** may include a thermocouple (or other suitable device for sensing and/or measuring a temperature, such as an infrared camera), which may or may not be included in the heater mat.

Vacuum chamber **112** may be at least partially defined by a flexible wall **136**. For example, wall **136** may be a vacuum bag made of a suitable polymer film (or other suitable material), that may be secured to composite material **124** to form chamber **112**. However, in other examples, composite material **124** may be completely disposed in chamber **112**, for example, when system **100** is used to manufacture composite material **124**. For example, wall **136** may completely surround composite material **124**. In either case, wall **136** may be configured to apply pressure to composite material **124** when chamber **112** is evacuated. Such pressure may be configured to compact at least a portion of composite material **124** (e.g., a composite material patch applied to a rework area of composite material **124**) as curing apparatus **104** applies thermal energy to a bond interface of composite material **124** associated with that compacted portion of composite material **124**. Application of the thermal energy may be configured to perform a cure cycle, such as an exemplary cure cycle depicted in FIG. **5**, which may cure the bond interface to a substantially cured state thereby securing the compacted portion of composite material **124** in position.

Curing apparatus **104** and electrical coupler **108** may be included in an apparatus, which may decrease vacuum leaks in chamber **112**, reduce possible damage to components of system **100**, and/or reduce a lay-up time of system **100**, as mentioned above, and as will be described below in further detail. For example, electrical coupler **108** may be connected to curing apparatus **104**. Coupler **108** may include a first set of one or more electrical contacts **140**. Contacts **140** may be electrically connected to electrical components **120** inside vacuum chamber **112**. For example, one or more conductors **148** may electrically connect electrical contacts **140** with associated electrical components **120**. Coupler **108** may be configured to hermetically extend through a hole **144** in flexible wall **136**. Such extension of coupler **108** may dispose electrical contacts **140** (e.g., at least a portion thereof) in a space outside of vacuum chamber **112**, a particular example of which is depicted in FIGS. **2** and **3** and described below in more detail.

For example, coupler **108** may be configured to extend through hole **144** in a substantially air-tight manner by hermetically clamping a region of flexible wall **136** surrounding an entire perimeter of hole **144**. For example, the hermetic clamping may be performed by an exterior portion of coupler **108**. An interior of coupler **108**, in which contacts **140** may be at least partially disposed, may be hermetically sealed with a suitable structure, device, apparatus, mechanism, material, or combination thereof for preventing air from infiltrating vacuum chamber **112** from the space outside of vacuum chamber **112** via the interior of coupler **108**. For example, the interior of coupler **108** may be sealed by a substantially non-porous potting compound from which electrical contacts **140** may protrude.

Electrical contacts **140** disposed in the space outside of vacuum chamber **112** may permit electrical interconnection of electrical components **120** with circuitry **116**. For example, coupler **108** may include one or more conductors **152** (e.g., a second set of corresponding electrical contacts that mate with contacts **140**) configured to electrically connect (or interconnect) electrical contacts **140** with circuitry **116**.

Heating element **128** may be configured to be powered by circuitry **116** (e.g., receive electrical current from circuitry **116**) via contacts **140** for applying thermal energy to composite material **124** to cure the composite material (e.g., a bond interface thereof) to the substantially cured state. For example, heating element **128** may include an electrically resistive component configured to convert received electrical current from circuitry **116** into the thermal energy, and direct that thermal energy to composite material **124**.

Temperature sensing device **132** may be configured to measure a temperature of composite material **124** (e.g., proximate the bond interface and/or heating element **128**). Device **132** may further be configured to transmit a signal indicative of the measured temperature of composite material **124** to circuitry **116** via electrical contacts **140**. Circuitry **116** may be configured to control power to heating element **128** based at least in part on the signal received from temperature sensing device **132**. For example, if the signal indicates that the temperature of composite material **124** is higher than a preferred temperature for an associated segment (or phase) of the cure cycle, then circuitry **116** may reduce power to heating element **128**. However, if the signal indicates that the temperature of composite material **124** is lower than a preferred temperature of the associated segment of the cure cycle, then circuitry **116** may increase power to heating element **128**.

Example 2

This example describes an illustrative system **200**, which is an embodiment of system **100**; see FIGS. **2** and **3**.

System **200** may include any apparatus, device, mechanism, structure, material, and/or combination thereof for suitably curing a composite material **204** (e.g., a bond interface between a rework area **206** of composite material **204** and a composite material patch **208**) inside a vacuum chamber, an exemplary formation (or lay-up) of which is shown in FIG. **3** and described further below in more detail.

For example, system **200** may include a curing apparatus (or heater mat) **212**, a flexible vacuum bag (or vacuum bag film, or flexible wall) **216**, and circuitry **218**. Curing apparatus **212** may include one or more electrical components, such as one or more heating elements **220** electrically connected to a bus bar **222**, for applying thermal energy to composite material **204** inside the vacuum chamber.

System **200** may further include an electrical coupler **224**. Coupler **224** may include mateable first and second connector portions **228**, **232**, and first and second washers (or gaskets) **236**, **240**. As shown, first connector portion **228** may be connected to (e.g., mounted to and/or on) heater mat **212**. First connector portion **228** may include a first set of one or more electrical contacts **244** (e.g., shown here as including three protruding male electrical contacts or pins, which may be solid). Electrical contacts **244** may be electrically connected to the electrical components of heater mat **212**. For example, electrical contacts **244** may be electrically connected to heating elements **220** via electrical connection to bus bar **222**. In some embodiments, at least one of electrical contacts **244** may be associated with a positive voltage power lead of heater mat **212**, at least one of electrical contacts **224** may be associated with a negative voltage power lead of heater mat **212**, and one of electrical contacts **224** may be associated with a circuit ground associated with heater mat **212**. Alternatively and/or additionally, one or more of electrical contacts **244** may be associated with a sensor element, which may be included in, or used in conjunction with, heater mat **212**.

Second connector portion **232** may include a second set of corresponding one or more electrical contacts **248** (e.g., shown here as including three female receptacle electrical contacts). Electrical contacts **248** may be configured for electrical connection to circuitry **218**, for example, via one or more electrically conductive cables **252**.

Electrical coupler **224** may include any suitable apparatus, device, mechanism, structure, material, and/or combination thereof configured for hermetic extension of coupler **224** through a hole **256** in film **216** and to electrically interconnect electrical contacts **244** with corresponding electrical contacts **248** when first and second connector portions **228**, **232** are mated. Such mating may electrically interconnect the one or more electrical components of curing apparatus **212** with circuitry **218** for operation of curing apparatus **212** in conjunction with circuitry **218** for curing the bond interface of composite material **204**.

For example, first connector portion **228** may be mounted on (or to) a first major face **212***a* of heater mat **212**. As shown, first connector portion **228** is a male connector portion including a base flange **260**, and a barrel **264**, one or more of which may be mounted to major face **212***a* of heater mat **212**. Base flange **260** may extend generally parallel to major face **212***a*. Barrel **264** may project away from major face **212***a* and base flange **260**. Base flange **260** may radially surround, extend from, and/or be connected to a lower portion of barrel **264**. An upper portion of barrel **264** may be configured to be received through hole **256** such that a region **266** of film **216** surrounding an entire perimeter of hole **256** contacts base flange **260** opposite major face **212***a*.

Second connector portion **232** may be a female connector portion. For example, second connector portion **232** may include an outer sidewall **268**, which may define an inner recess **272** for receiving (e.g., mating with) barrel **264**.

Coupler **224** may be configured to clamp region **266** between second connector portion **232** and base flange **260** when connector portions **228**, **232** are mated (e.g., when barrel **264** is received in recess **272**). Such clamping may form a hermetic (e.g., substantially air-tight) seal between base flange **260** and region **266**.

More specifically, in an exemplary lay-up (e.g., bagging process) of system **200**, rework area **206** may be identified. Rework area **206** may correspond to a damaged area of composite material **204**, and/or an area of composite material **204** in which it is desired to add a new composite material feature. In either case, rework area **206** may be prepared by tapering edges of rework area **206**, and/or cleaning a surface of rework area **206**. Patch **208** may be positioned in (or proximate) rework area **206** with a bond interface **276** (see FIG. **3**), which may include a layer of adhesive (e.g., resin matrix material) sandwiched between two layers of permeable positioning fabric (e.g., reinforcement material), a suitable example of which is described and shown in U.S. Pat. No. 9,545,782, which is hereby incorporated by reference in its entirety for all purposes. It should be noted that bond interface **276** is not shown in FIG. **2** to simplify the illustration, but that when system **200** is laid-up, for example as shown in FIG. **3**, bond interface **276** may be disposed between patch **208** and rework area **206**.

Curing apparatus **212** may be positioned on a cure zone of (e.g., associated with) composite material **204**. For example, the cure zone may be associated with bond interface **276** between patch **208** and rework area **206**. In some embodiments, the cure zone may alternatively and/or additionally be associated with patch **208**, for example, if patch **208** includes uncured composite material components, such as a one or more layers of pre-preg. For example, positioning curing apparatus **212** on the cure zone may involve disposing curing apparatus **212** proximate patch **208** and bond interface **276** adjacent rework area **206**.

Though not shown for simplicity of illustration, positioning curing apparatus **212** on the cure zone may involve positioning one or more of a perforated release film, a bleeder layer, an unperforated release film, and a breather layer serially upon the cure zone between patch **208** and curing apparatus **212**. The perforated release film may be a thin non-bondable film with relatively small perforations at regular spacings to allow air and excess resin extraction from the bond interface. The perforated release film may be configured to prevent the remaining bagging materials (e.g., the bleeder layer, the unperforated release film, the breather layer, curing apparatus **212**, and film **216**) from becoming bonded to composite material **204** during a cure cycle while still allowing air and excess resin extraction. The bleeder may be a thin fabric layer that may be placed over the perforated release film to provide an air evacuation path and absorb excess resin. The unperforated release film may be made of the same material as the perforated release film, but not perforated. The unperforated release film may be configured to prevent excess resin from flowing to other bagging components, such as the bleeder layer, curing apparatus **212**, and film **216**. The breather layer may include a relatively heavy fabric material or non-woven material for providing an air path for air extraction from inside the vacuum chamber and provide insulation.

A major face **212***b* of curing apparatus **212** opposite major face **212***a* may be positioned on the bleeder layer opposite patch **208**, bond interface **276**, and rework area **206**. Film **216** may be disposed over curing apparatus **212** opposite composite material **204**. Film **216** may be secured (e.g., sealed) to composite material **204** with an adhesive interface **280** (e.g., double-sided vacuum sealant tape) to form the vacuum chamber, generally indicated at **282** in FIG. **3**. Adhesive interface **280** may be disposed on a second major face (or surface) **216***b* of film **216**, which may be opposite first major face **216***a*. As shown, curing apparatus **212** may be disposed in formed vacuum chamber **282**.

Returning to FIG. **2**, hole **256** may be formed (e.g., cut) in film **216** before, after, and/or while film **216** is disposed on curing apparatus **212** opposite composite material **204**. For example, in some embodiments, film **216** may be provided from the manufacturer with hole **256** precut, and in other embodiments, hole **256** may be formed after film **216** is secured to composite material **204**. As shown, hole **256** may have a slightly larger diameter than barrel **264**, which may allow barrel **264** to extend through hole **256** out of vacuum chamber **282**.

In an exemplary process of sealing hole **256** with electrical coupler **224**, washer **240** may be disposed on barrel **264** protruding through hole **256**, such that washer **240** surrounds barrel **264** and contacts region **266** on first major face **216***a* of film **216** facing away from composite material **204**, as can be seen in FIG. **3**. Washer **236** may be similarly disposed around barrel **264**, but contacting washer **240** opposite film **216** instead of region **266**. Second connector portion **232** may be tightened (e.g., threaded) onto barrel **264** to draw connector portions **228**, **232** toward one another thereby creating a hermetic (e.g., air tight, and/or vacuum tight) seal between region **266** and base flange **260**. For example, outer sidewall **268** may include a threaded interior surface corresponding with a threaded exterior surface of barrel **264**. Outer sidewall **268** may be configured to rotate relative to electrical contacts **248**. Tightening second connector portion **232** onto first connector portion **228** may involve inserting barrel **264** into inner recess **272**, and rotating outer sidewall **268** relative to electrical contacts **248** to thread outer sidewall **268** onto barrel **264** thereby drawing connector portions **228**, **232** toward one another. As second connector portion **232** is drawn toward first connector portion **228**, an opening of inner recess **272** (e.g., which may be formed by a lower portion of outer sidewall **268**) may apply a pressing force against washer **240** via washer **236**. The pressing force may press washer **240** against first major face **216***a* of film **216** in region **266** to form the hermetic seal between base flange **260** and second major face **216***b* of film **216** in region **266**. For example, washer **240** may be made of substantially resilient and/or compliant material, such as rubber, for providing a compliant interface and pressure seal by conformingly pressing against region **266** opposite flange **260**. Further, washer **236** may be made of a substantially rigid material, such as a suitable metal, for providing generally uniform application of pressure across washer **240** transmitted from outer sidewall **268**.

Such hermetic clamping of region **266** between connector portions **228**, **232**, in conjunction with a hermetic sealing of an interior of barrel **264**, as will be described below in further detail, may permit the hermetic extension of electrical contacts **244** through hole **256** and out of vacuum chamber **282**. Thus, time consuming and vacuum leak prone electrical interconnection of pre-existing system and methods that involve routing electrical power leads and sensor wires out of the vacuum chamber proximate the adhesive interface between the vacuum bag film and the composite material may be avoided.

Further, as shown in FIG. **3**, the mating of connector portions **228**, **232** may be configured to electrically interconnect electrical contacts **244** with electrical contacts **248**, for example, by electrical contacts **244** being received in and brought into physical and/or electrical contact with corresponding electrical contacts **248**. For example, the first set of electrical contacts **244** may extend through an interior of barrel **264** and away from heater mat **212**. The interior of barrel **264** surrounding electrical contacts **244** may be hermetically sealed with a substantially non-porous potting material (or compound) **276**. Potting material **276** may be electrically insulating and/or may have a lower thermal conductivity than a material of contacts **248**, which may correspondingly prevent short circuiting of the contacts and/or cracking of the hermetic seal formed by the potting material. For example, contacts **248** may be made of copper, or other material with a relatively high thermal conductivity, and potting material **276** may be made from an epoxy resin or material with a suitably low thermal conductivity.

At least a portion of one or more of electrical contacts **244** may protrude from potting material **276** opposite heater mat **212**. For example, first ends **244***a*, **244***b*, **244***c* of respective first, second, and third electrical contacts of electrical contacts **244** may extend out of potting material **276**. Female receptacle electrical contacts **248***a*, **248***b*, **248***c* of electrical contacts **248** may be configured to receive and electrically connect to respective first ends **244***a*, **244***b*, **244***c* when connector portions **228**, **232** are mated, as shown.

As described above, the mating of contacts **244**, **248** may electrically interconnect circuitry **218** with the one or more electrical components of (or associated with) heater mat **212**, such as heating elements **220** and/or a sensing element **280**. For example, contacts **248***a*, **248***b*, **248***c* may be configured for electrical connection to circuitry **218** via respective electrical conductors **284***a*, **284***b*, **284***c*, which may be electrically insulated from one another inside cable **252**. Further, first ends **244***a*, **244***b* may be electrically connected to bus bar **222** (and/or heating element **220**) via respective electrical conductors **288***a*, **288***b*, and first end **244***c* may be electrically connected to sensing element **280** via electrical conductor **288***c*. In some embodiments, electrical conductors **288***a*, **288***b*, **288***c* may include (or be) second ends of contacts **244** corresponding respectively with first ends **244***a*, **244***b*, **244***c*.

In some embodiments, as shown in FIG. **3**, securing film **216** to composite material **204** (with adhesive interface **280**), and hermetically sealing the hole in film **216** via the mating action of connector portions **228**, **232** may form vacuum chamber **282**. Vacuum chamber **282** may be at least partially defined by film **216**. Heater mat **212** may be disposed in vacuum chamber **282**, for example between film **216** and composite material **204**.

In operation, vacuum chamber **282** may be substantially evacuated to a substantially evacuated state, for example, via a vacuum port assembly **292** coupled to film **216** as depicted in FIG. **2**, but not shown in FIG. **3** to simplify illustration. Film **216** may be configured to apply a pressing force (e.g., of about 1 atmosphere, which at sea level may be equivalent to 14.7 pounds per square inch or 101,353.0 Newtons per square meter) against composite material **204** (e.g., to compact patch **208** and bond interface **276** onto rework area **206**) via heater mat **212** when vacuum chamber **282** is substantially evacuated, and as application of thermal energy from heating elements **220** at least partially cures composite material **204** (e.g., bond interface **276** associated with composite material **204** and patch **208**) to a substantially cured state. For example, heating elements **220** may be configured to receive electrical power from circuitry **218** via electrical interconnection of first ends **244***a*, **244***b* with respective contacts **248***a*, **248***b*. Heating elements **220** may be configured to convert the received electrical power into thermal energy. Heating elements **220** may be configured to apply that thermal energy to bond interface **276**. For example, heater mat **212** may include one or more components and/or functionalities described in one or more of U.S. Pat. No. 8,330,086 and U.S. Pat. No. 9,375,884, both of which are hereby incorporated by reference in their entireties for all purposes.

Circuitry **218** may be configured to control the application of thermal energy from heating elements **220** to composite material **204**, such that composite material **204** (e.g., associated bond interface **276**) is suitably cured to the substantially cured state. For example, the exemplary cure cycle depicted in FIG. **5** (or another suitable cure cycle), may be input and/or stored in circuitry **218**. Sensing element **280** may be configured to continuously and/or intermittently measure the temperature of the cure zone (e.g., composite material **204**, bond interface **276**, and/or patch **208**). Sensing element **280** may be configured to transmit one or more signals indicative of the measured temperature (or temperatures) to circuitry **218** via electrical interconnection of end **244***c* with contact **248***c*. Circuitry **218** may be configured to receive the one or more signals. Based at least in part on the received one or more signals, circuitry **218** may be configured to adjust and/or maintain the transmission of electrical power to heating elements **220**. For example, if the one or more received signals indicate that the temperature of composite material **204** (e.g., associated bond interface **276**) is higher than a preferred temperature for an associated segment (or phase) of the cure cycle, then circuitry **218** may reduce power to heating elements **220**. However, if the one or more received signals indicate that the temperature of composite material **204** is lower than a preferred temperature of the associated segment of the cure cycle, then circuitry **218** may increase power to heating element **220**. While sensing element **280** is schematically depicted in FIG. **3**, it should be noted that in various embodiments, sensing element **280** may be indexed with one or more of heating elements **220**, and in some embodiments may include a plurality of sensing elements indexed to an array of heating elements. Further, in some embodiments, the sensing element(s) may be powered by circuitry **218** via electrical interconnection of electrical contacts **244**, **248**.

Various embodiments may be configured to maintain vacuum chamber **282** in the substantially evacuated state such that the atmospheric pressure inside vacuum chamber **282** increases by no more than 127 mmHg in a five minute interval via one or more of adhesive interface **280** and hole **256**. In some embodiments, such as those with more restricted parameters, the system may be configured to maintain vacuum chamber **282** in the substantially evacuated state such that the atmospheric pressure inside vacuum chamber **282** increases by no more than 51 mmHg in a five minute interval via one or more of adhesive interface **280** and hole **256**. For example, before and/or during application of thermal energy to composite material **204**, vacuum chamber **282** may be leak tested. For example, a pressure gauge **294** (see FIG. **2**—not shown in FIG. **3** to simplify illustration) may be coupled to film **216** and configured to measure the atmospheric pressure inside vacuum chamber **282**. Such maintenance of vacuum chamber **282** in the substantially evacuated state (e.g., as measured by gauge **294**) may be permitted by the secure hermetic seal formed by the clamping of region **266** by internally hermetically sealed electric coupler **224** and/or by the avoidance of routing electrical leads for curing apparatus **212** out of the vacuum chamber through an interface of the vacuum bag film and the composite material.

Additional features of system **200** may further increase a durability and/or efficiency of system **200**. For example, one or more features of coupler **224** may be configured to prevent damage to film **216** proximal hole **256**. For example, base flange **260** may include a tapered outer perimeter (or region) **260***a* that slopes away from a central substantially flat region **260***b* of base flange **260**, as can be seen in FIG. **3**. Surface **216***b* in region **266** (see FIG. **2**) may contact flat region **260***b*. Tapered outer perimeter **260***a* may be configured to allow film **216** proximal region **266** to slope away from rigid washer **236** (as shown in FIG. **3**), which may prevent rigid washer **236** from contacting and/or puncturing film **216**, if for example, connector **232** is "over-tightened" on barrel **264**. Further, upper and/or lower surfaces of respective flat region **260***b* and/or tapered outer perimeter **260***a* may be covered in silicon rubber (or other suitably compliant and/or resilient material), which may improve hermetic sealing of film **216** to base flange **260**, and/or decrease abrasion of film **216** by base flange **260**. Moreover, potting material **276** may be disposed outside an active heating zone associated with heating elements **220**, which may further prevent the interior hermetic seal formed by potting material **276** from cracking or may otherwise limit degradation of the interior seal of connector portion **228** over time.

In some embodiments, one or more components of coupler **224**, such as base flange **260**, barrel **264**, and/or outer sidewall **268** may be made of a material with a relatively low thermal conductivity (e.g., nylon 6-6), which may prevent these components from acting as heat sinks. Such a construction may significantly prevent thermal energy from being drawn away from heating elements **220** and composite material **204** by these components of coupler **224**, thereby increasing an efficiency of curing apparatus **212** and/or reducing thermal expansion of these components of coupler **224**. Such a reduction of thermal expansion, particularly that associated with barrel **264** and potting material **276**, may extend an operational life of coupler **224**, as the expansion (and contraction) of these materials may increase a likelihood that the interior hermetic seal formed by potting material **276** may become damaged over time.

Although one embodiment of system **200** is shown in FIGS. **2** and **3**, it should be noted that components thereof may be configured in various alternative ways. For example, though contacts **244** are shown protruding out of the upper portion of barrel **264** in which potting material **276** is disposed, in other embodiments, contacts **244** may protrude from potting material **276** inside of barrel **264** and may not extend out of the upper portion of barrel **264**. Such a configuration may further prevent film **216** from being torn or otherwise damaged by contacts **244** during the bagging process. Further, while potting material **276** is shown as extending through a minority of a height of barrel **264**, in other embodiments, the potting material may extend through a majority of the height of barrel **264**, which may increase the hermetic sealing of the interior of barrel **264**. Moreover, while connector portion **228** connected to curing apparatus **212** is shown to be a male connector portion, in other embodiments connector portion **228** may be a female connector portion and connector portion **232** may be a male connector portion configured to extend through hole **256** and be received in connector portion **228**. In some embodiments, contacts **244** may include female receptacles protruding from (or recessed into) potting material **276**, and contacts **248** may include male contacts configured to be received therein. In other embodiments, contacts **244**, **248** may be electrically connected but not mate with each other when connector portions **228**, **232** are mated. In some embodiments, an interior of connector portion **232** may be hermetically sealed with a suitable potting material in addition to, or instead of, the interior of connector portion **228** being hermetically sealed with potting material **276**. Further, while female receptacle contacts **248***a*, **248***b*, **248***c* are shown in FIG. **3** as including distal upper walls that are contacted by respective ends **244***a*, **244***b*, **244***c* when connector portions **228**, **232** are mated, in some embodiments these female receptacle contacts may be elongated and/or not include upper walls, which may permit hermetic sealing of vacuum bag films having varying thicknesses and still allow for sufficient electrical interconnection of the respective electrical contacts.

Example 3

This example describes a method; see FIG. **4**.

FIG. **4** is a flowchart illustrating steps in an illustrative method, and may not recite the complete process. FIG. **4** depicts multiple steps of a method, generally indicated at **400**, which may be performed in conjunction with a curing apparatus and an electrical coupler, such as either of curing apparatuses **104**, **212** and couplers **108**, **224**, according to aspects of the present disclosure. Although various steps of method **400** are described below and depicted in FIG. **400**, the steps need not necessarily all be performed, and in some cases may be performed in a different order than the order shown.

As shown, method **400** may include a step **402** of positioning a curing apparatus on a cure zone of a composite material. The curing apparatus may include one or more electrical components electrically connected to a first set of one or more electrical contacts. In some embodiments, the first set of one or more electrical contacts may be included in a first connector portion of a coupler. In some embodiments, the curing apparatus may include a heater mat, such as heater mat **212**, to which the first connector portion may be mounted. In some embodiments, positioning the curing apparatus may involve (or be proceeded by) defining the cure zone by applying a composite material patch and a bond interface to a rework area of the composite material. In some embodiments, step **402** may involve (or be proceeded by) disposing one or more of a perforated release film, a bleeder, an unperforated release film, and a breather proximate the patch opposite the composite material.

Method **400** may further include a step **404** of disposing a vacuum bag film over the curing apparatus opposite the composite material. At step **404**, disposing the vacuum bag film over the curing apparatus may not necessarily involve disposing the vacuum bag film vertically above the curing apparatus. For example, the cure zone may be associated with an under-side of a composite material, such as a lower surface of a wing of a commercial airliner, in which case step **404** may involve disposing the vacuum bag film over the curing apparatus opposite the composite material with the vacuum bag film substantially vertically below the curing apparatus.

Method **400** may further include a step **406** of securing the vacuum bag film to the composite material with an adhesive interface to form a vacuum chamber in which the curing apparatus is disposed. For example, the adhesive interface may include double-sided vacuum sealant tape, or any other suitable adhesive, device, mechanism, structure, apparatus, or combination thereof for substantially hermetically sealing a perimeter region of the vacuum bag film to the composite material.

Method **400** may further include a step **408** of substantially hermetically extending the first set of one or more electrical contacts through a hole in the vacuum bag film. For example, the first set of one or more electrical contacts may be included in a electrical coupler, such as coupler **224** of FIGS. **2** and **3**. In particular, the electrical coupler may have a hermetically sealed interior through which the first set of one or more electrical contacts protrude out of the vacuum chamber. Further, an exterior of the electrical coupler may be configured to hermetically clamp a perimeter region surrounding the hole, such as region **266** surrounding hole **256** in FIG. **2**, thereby substantially preventing atmospheric pressure from traversing the hole (e.g., between the perimeter of the hole and the exterior of the electrical coupler).

In some embodiments, step **408** may be carried out prior to step **406**. For example, method **400** may involve hermetically clamping the perimeter region of the hole with the exterior of the electrical coupler prior to securing the vacuum bag film to the composite material. For example, before securing the vacuum bag film to the composite material, a user may use their hand (or other tool) to apply pressure against a base flange of the electrical coupler, which may be mounted to the curing apparatus, to reduce transmission of torque from the electrical coupler to the curing apparatus as the electrical coupler is operated to clamp the perimeter region of the hole.

Method **400** may further include a step of substantially evacuating the vacuum chamber to a substantially evacuated state (e.g., after the hole has been hermetically sealed and vacuum bag film has been secured to the composite material). In the substantially evacuated state, the vacuum bag film may apply a pressing force against the composite material via the curing apparatus (e.g., thereby pressing or compacting the patch and the bond interface toward the rework area).

Method **400** may further include a step of maintaining the vacuum chamber in the substantially evacuated state such that an atmospheric pressure (e.g., 14.7 psi) inside the vacuum chamber increases by no more than 127 mmHg in a five minute interval of time via one or more of the adhesive interface and the hole. In some embodiments, the maintaining step may involve maintaining the vacuum chambing in the substantially evacuated state such that an atmospheric pressure inside the vacuum chamber increases by no more than 51 mmHg in 5 minutes interval. Such maintenance of the vacuum chamber in the substantially evacuated state may ensure that the composite material (e.g., the associated patch and/or bond interface) is suitable compressed during a cure cycle, which may be performed by the one or more electrical components of the curing apparatus in conjunction with circuitry disposed outside of the vacuum chamber, as will be describe below in more detail.

Method **400** may further include a step of electrically interconnecting the first set of one or more electrical contacts with a second set of corresponding one or more electrical contacts. The second set may be included in a second connector portion of the coupler, and may be configured for electrical connection to the circuitry disposed outside of the vacuum chamber.

In some embodiments, the one or more electrical components of the curing apparatus may be configured to operate in conjunction with the circuitry by at least one or more of (a) receiving electrical power from the circuitry via electrical interconnection of the first and second sets for applying thermal energy to the composite material, and (b) transmitting to the circuitry via electrical interconnection of the first and second sets a signal indicative of a measure temperature of the composite material for monitoring application of thermal energy to the composite material. For example, when the first and second sets are electrically interconnected, the circuitry, such as circuitry **116** or **218**, may transmit the electrical power to the one or more electrical components of the curing apparatus, such as heating element **128** or heating elements **220**. The one or more electrical components of the curing apparatus may use (e.g., convert) the received electrical power to apply thermal energy to the composite material (e.g., the associated bond interface) to cure the composite material (e.g., the associated bond interface) to a substantially cured state. For example, the applied thermal energy may be configured to perform a suitable cure cycle on the composite material (e.g., the associated bond interface), such as the cure cycle depicted in FIG. **5**. For example, the one or more electrical components may include a temperature sensing element, such as a thermocouple, infrared camera, or other suitable device, configured to measure the temperature of the composite material, and transmit to the circuitry via the electrical interconnection of the first and second sets the signal indicative of the measured temperature. Based at least in part on the signal, or a plurality of such signals, the circuitry may monitor the application of the thermal energy. For example, the circuitry may be configured to compare the measured temperatures indicated in the signal(s) to the desired (or input) cure cycle. Based on such a comparison, the circuitry may notify a user if the temperature is too high or too low, and/or accordingly adjust a level of electrical power transmitted to the thermal energy applying components of the curing apparatus.

It should be noted that the thermal energy applying components may not directly apply the thermal energy to the composite material. For example, these components may include one or more microwave emitters configured to generate and direct microwaves toward the composite material, thereby indirectly applying thermal energy via molecular excitation of the associated bond interface.

In some embodiments, step **408** and the step of electrically interconnecting may be performed at least partially concurrently. For example, the second connector portion may mate with the first connector portion to electrically interconnect the second set of corresponding one or more electrical contacts with the first set of one or more electrical contacts. Such mating may also clamp the region of the vacuum bag film surrounding an entire perimeter of the hole between the first and second connector portions thereby hermetically sealing the hole.

However, in other embodiments, step **408** of hermetically extending and the step of electrically interconnecting may not be performed at least partially concurrently. For example, an exterior of the first connector portion may be configured to clamp the region of the vacuum bag film surrounding the hole. For example, the exterior of the first connector portion may include threaded ring configured to clamp the region of the vacuum bag film onto a base flange of the first connector portion to hermetically dispose the first set of one or more electrical contacts outside of the vacuum chamber. In such an embodiment, the second set of one or more electrical contacts may be electrically interconnected with the first set after (or before) the region of the vacuum bag film is clamped by the first connector portion.

In some embodiments, method **400** may further include one or more steps associated with a debagging process. For example, when the bond interface has been cured to the substantially cured state (e.g., reached an end of the cure cycle associated with a particular measured temperature), the circuitry may notify a user. The user may un-mate (e.g., unscrew) the second connector portion from the first connector portion, and may electrically disconnect the first and second sets from one another. The user may unsecure the vacuum bag film from the composite material, and remove the first connector portion from the hole in the vacuum bag film. In some embodiments, the vacuum bag film may be disposable, in which case the vacuum bag film may be discarded (or recycled) after it is unsecured from the composite material. The curing apparatus (and, if used, the perforated release film, the bleeder, the unperforated release film, and the breather) may be removed from the cure zone, and a cure (or bond) of the composite material (e.g., associated with the patch, bond interface, and/or rework area) may be inspected.

Example 4

This example describes an illustrative cure cycle (or process) for bonding materials, which may be used in conjunction with any of the apparatuses and/or methods described herein; see FIG. **5**.

FIG. **5** shows a chart of an illustrative cure cycle, generally indicated at **500**. Cycle **500** may include a heat ramp-up phase **504**, a dwell phase **508**, and a cool down phase **512**.

Prior to cycle **500**, materials may be prepared to be bonded together at a bond interface in a bonding or cure zone, which may involve preparing a damaged area and/or applying a patch. A vacuum bag film, or other pressure reduction device, may be applied to the bonding zone to hold the materials together. An apparatus for bonding the materials may be used to define the bonding zone. In some embodiments, the vacuum bag may be placed over the apparatus (e.g., after the apparatus has defined the bonding zone).

Phase **504** may begin at a first predetermined temperature (e.g., of a bond interface defined between the materials), such as at 54 degrees Celsius. In some embodiments, emitted radiation from the apparatus of any of the foregoing examples may be used to heat the bond interface. In some embodiments, the materials (and/or the bond interface) may be initially heated by another source, such as a heat gun, which may be used to heat tack an adhesive layer and/or the materials in place. Phase **504** may involve increasing the temperature of the bond interface at a first predetermined rate, such as at a rate in a range of about 0.5 to 3 degrees Celsius per minute. Phase **504** may continue until the bond interface reaches a second predetermined temperature, which may be a cure (or cured) temperature of the bond interface, such as a temperature of 177 degrees Celsius plus or minus 6 degrees Celsius.

Phase **508** may begin when the bond interface reaches the second predetermined temperature. Phase **508** may involve holding or maintaining the second predetermined temperature for a predetermined duration of time, such as 150 to 210 minutes. Maintaining the second predetermined temperature for the predetermined duration of time may form a suitable bond between the materials (e.g., at the bond interface).

Phase **512** may start when the predetermined duration of time has lapsed. Phase **512** may involve decreasing the temperature of the bond interface at a second predetermined rate, such as at a rate that is less than or equal to 3 degrees Celsius per minute. The second predetermined rate may be a maximum rate at which the temperature of the bond interface can be reduced without reducing a strength of the bond. Phase **512** may continue until the bond interface reaches a third predetermined temperature, such as a temperature at or below 60 degrees Celsius. Once the bond interface has reached the third predetermined temperature, pressure inside the vacuum bag (e.g., pressure inside a vacuum chamber formed at least partially by the vacuum bag) may be released, the vacuum bag and the apparatus may be removed, and the bond between the materials may be inspected.

Example 5

A curing apparatus, such as the one shown and described with reference to FIGS. **2** and **3** (e.g., heater mat **212**), may be controlled at least partially (or in some cases, completely) by a data processing system, such as data processing system **600** shown in FIG. **6**. For example, data processing system **600** may be an illustrative data processing system, which may be used for implementing one or more of the components and/or functionalities of circuitry **218** of FIGS. **2-3** (and/or circuitry **116** of FIG. **1**), or any of the associated components and/or functionalities described herein.

In this illustrative example, data processing system **600** includes communications framework **602**. Communications framework **602** provides communications between processor unit **604**, memory **606**, persistent storage **608**, communications unit **610**, input/output (I/O) unit **612**, and display **614**. Memory **606**, persistent storage **608**, communications unit **610**, input/output (I/O) unit **612**, and display **614** are examples of resources accessible by processor unit **604** via communications framework **602**.

Processor unit **604** serves to run instructions that may be loaded into memory **606**. Processor unit **604** may be a number of processors, a multi-processor core, or some other type of processor, depending on the particular implementation. Further, processor unit **604** may be implemented using a number of heterogeneous processor systems in which a main processor is present with secondary processors on a single chip. As another illustrative example, processor unit **604** may be a symmetric multi-processor system containing multiple processors of the same type.

Memory **606** and persistent storage **608** are examples of storage devices **616**. A storage device is any piece of hardware that is capable of storing information, such as, for example, without limitation, data, program code in functional form, and other suitable information either on a temporary basis or a permanent basis.

Storage devices **616** also may be referred to as computer readable storage devices in these examples. Memory **606**, in these examples, may be, for example, a random access memory or any other suitable volatile or non-volatile storage device. Persistent storage **608** may take various forms, depending on the particular implementation.

For example, persistent storage **608** may contain one or more components or devices. For example, persistent storage **608** may be a hard drive, a flash memory, a rewritable optical disk, a rewritable magnetic tape, or some combination of the above. The media used by persistent storage **608** also may be removable. For example, a removable hard drive may be used for persistent storage **608**.

Communications unit **610**, in these examples, provides for communications with other data processing systems or devices. In these examples, communications unit **610** is a network interface card. Communications unit **610** may provide communications through the use of either or both physical and wireless communications links.

Input/output (I/O) unit **612** allows for input and output of data with other devices that may be connected to data processing system **600**. For example, input/output (I/O) unit **612** may provide a connection for user input through a keyboard, a mouse, and/or some other suitable input device. Further, input/output (I/O) unit **612** may send output to a printer. Display **614** provides a mechanism to display information to a user.

Instructions for the operating system, applications, and/or programs may be located in storage devices **616**, which are in communication with processor unit **604** through communications framework **602**. In these illustrative examples, the instructions are in a functional form on persistent storage **608**. These instructions may be loaded into memory **606** for execution by processor unit **604**. The processes of the different embodiments may be performed by processor unit **604** using computer-implemented instructions, which may be located in a memory, such as memory **606**.

These instructions are referred to as program instructions, program code, computer usable program code, or computer readable program code that may be read and executed by a processor in processor unit **604**. The program code in the different embodiments may be embodied on different physical or computer readable storage media, such as memory **606** or persistent storage **608**.

Program code **618** is located in a functional form on computer readable media **620** that is selectively removable and may be loaded onto or transferred to data processing system **600** for execution by processor unit **604**. Program code **618** and computer readable media **620** form computer program product **622** in these examples. In one example, computer readable media **620** may be computer readable storage media **624** or computer readable signal media **626**.

Computer readable storage media **624** may include, for example, an optical or magnetic disk that is inserted or placed into a drive or other device that is part of persistent storage **608** for transfer onto a storage device, such as a hard drive, that is part of persistent storage **608**. Computer readable storage media **624** also may take the form of a persistent storage, such as a hard drive, a thumb drive, or a flash memory, that is connected to data processing system **600**. In some instances, computer readable storage media **624** may not be removable from data processing system **600**.

In these examples, computer readable storage media **624** is a physical or tangible storage device used to store program code **618** rather than a medium that propagates or transmits program code **618**. Computer readable storage media **624** is also referred to as a computer readable tangible storage device or a computer readable physical storage device. In other words, computer readable storage media **624** is a media that can be touched by a person.

Alternatively, program code **618** may be transferred to data processing system **600** using computer readable signal media **626**. Computer readable signal media **626** may be, for example, a propagated data signal containing program code **618**. For example, computer readable signal media **626** may be an electromagnetic signal, an optical signal, and/or any other suitable type of signal. These signals may be transmitted over communications links, such as wireless communications links, optical fiber cable, coaxial cable, a wire, and/or any other suitable type of communications link. In other words, the communications link and/or the connection may be physical or wireless in the illustrative examples.

In some illustrative embodiments, program code **618** may be downloaded over a network to persistent storage **608** from another device or data processing system through computer readable signal media **626** for use within data processing system **600**. For instance, program code stored in a computer readable storage medium in a server data processing system may be downloaded over a network from the server to data processing system **600**. The data processing system providing program code **618** may be a server computer, a client computer, or some other device capable of storing and transmitting program code **618**.

The different components illustrated for data processing system **600** are not meant to provide architectural limitations to the manner in which different embodiments may be implemented. The different illustrative embodiments may be implemented in a data processing system including components in addition to and/or in place of those illustrated for data processing system **600**. Other components shown in FIG. YY can be varied from the illustrative examples shown. The different embodiments may be implemented using any hardware device or system capable of running program code. As one example, data processing system **600** may include organic components integrated with inorganic components and/or may be comprised entirely of organic components excluding a human being. For example, a storage device may be comprised of an organic semiconductor.

In another illustrative example, processor unit **604** may take the form of a hardware unit that has circuits that are manufactured or configured for a particular use. This type of hardware may perform operations without needing program code to be loaded into a memory from a storage device to be configured to perform the operations.

For example, when processor unit **604** takes the form of a hardware unit, processor unit **604** may be a circuit system, an application specific integrated circuit (ASIC), a programmable logic device, or some other suitable type of hardware configured to perform a number of operations. With a programmable logic device, the device is configured to perform the number of operations. The device may be reconfigured at a later time or may be permanently configured to perform the number of operations. Examples of programmable logic devices include, for example, a programmable logic array, a field programmable logic array, a field programmable gate array, and other suitable hardware devices. With this type of implementation, program code **618** may be omitted, because the processes for the different embodiments are implemented in a hardware unit.

In still another illustrative example, processor unit **604** may be implemented using a combination of processors found in computers and hardware units. Processor unit **604** may have a number of hardware units and a number of processors that are configured to run program code **618**. With this depicted example, some of the processes may be implemented in the number of hardware units, while other processes may be implemented in the number of processors.

In another example, a bus system may be used to implement communications framework **602** and may be comprised of one or more buses, such as a system bus or an input/output bus. Of course, the bus system may be implemented using any suitable type of architecture that provides for a transfer of data between different components or devices attached to the bus system.

Additionally, communications unit **610** may include a number of devices that transmit data, receive data, or both transmit and receive data. Communications unit **610** may be, for example, a modem or a network adapter, two network adapters, or some combination thereof. Further, a memory may be, for example, memory **606**, or a cache, such as that found in an interface and memory controller hub that may be present in communications framework **602**.

The flowcharts and block diagrams described herein illustrate the architecture, functionality, and operation of possible implementations of systems, methods, and computer program products according to various illustrative embodiments. In this regard, each block in the flowcharts or block diagrams may represent a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function or functions. It should also be noted that, in some alternative implementations, the functions noted in a block may occur out of the order noted in the drawings. For example, the functions of two blocks shown in succession may be executed substantially concurrently, or the functions of the blocks may sometimes be executed in the reverse order, depending upon the functionality involved.

Example 6

This section describes additional aspects and features of embodiments, presented without limitation as a series of paragraphs, some or all of which may be alphanumerically designated for clarity and efficiency. Each of these paragraphs can be combined with one or more other paragraphs, and/or with disclosure from elsewhere in this application, including the materials incorporated by reference, in any suitable manner. Some of the paragraphs below expressly refer to and further limit other paragraphs, providing without limitation examples of some of the suitable combinations.

A0. An apparatus comprising: a heater mat including one or more electrical components for applying thermal energy to a composite material inside a vacuum chamber at least partially defined by a flexible wall configured to apply a pressing force against the composite material via the heater mat when the vacuum chamber is substantially evacuated and as the application of the thermal energy at least partially cures the composite material to a substantially cured state; and an electrical coupler including male and female connector portions one of which is connected to the heater mat, the connector portion that is connected to the heater mat including a first set of one or more electrical contacts electrically connected to the one or more electrical components of the heater mat, the other of the connector portions including a second set of one or more electrical contacts configured for electrical connection to circuitry disposed outside of the vacuum chamber, wherein the coupler is configured to extend through and hermetically seal a hole in the flexible wall, and to electrically interconnect the first and second sets of one or more electrical contacts when the male and female connector portions are mated for electrical interconnection of the one or more electrical components of the heater mat disposed inside the vacuum chamber with the circuitry disposed outside of the vacuum chamber.

A1. The apparatus of paragraph A0, wherein the connector portion that is connected to the heater mat is mounted on a major face of the heater mat.

A2. The apparatus of paragraph A1, wherein the connector portion that is mounted on the major face of the heater mat is the male connector portion.

A3. The apparatus of paragraph A2, wherein the male connector portion includes a base flange and a barrel, with the base flange extending generally parallel to the major face, the barrel projecting away from the major face and the base flange, the first set of one or more electrical contacts extending through an interior of the barrel and away from the heater mat, and the base flange radially surrounding a lower portion of the barrel, an upper portion of the barrel being configured to be received through the hole in the flexible wall such that a region of the flexible wall surrounding an entire perimeter of the hole contacts the base flange opposite the major face of the heater mat, the coupler being configured to clamp the region of the flexible wall between the female connector portion and the base flange when the male and female connector portions are mated to form a hermetic seal between the base flange and the region of the flexible wall.

A4. The apparatus of paragraph A3, wherein the interior of the barrel is hermetically sealed with a potting material, and the first set of one or more electrical contacts protrude from the potting material opposite the heater mat.

A5. The apparatus of paragraph A4, wherein the second set of one or more electrical contacts are one or more female

electrical contacts configured to receive the first set of one or more electrical contacts protruding from the potting material.

A6. The apparatus of paragraph A4, wherein the potting material has a lower thermal conductivity than a material of the first set of one or more electrical contacts.

A7. The apparatus of paragraph A3, wherein the base flange extends from and is connected to the lower portion of the barrel.

A8. The apparatus of paragraph A0, wherein the one or more electrical components of the heater mat include at least one heating element powered by the circuitry disposed outside the vacuum chamber via electrical interconnection of the first set of one or more electrical contacts with the second set of one or more electrical contacts, the heating element being configured to apply at least a portion of the thermal energy to the composite material.

A9. The apparatus of paragraph A0, wherein the one or more electrical components of the heater mat include a sensor element configured to measure a temperature of the composite material for monitoring application of the thermal energy.

B0. An apparatus comprising: a curing apparatus including one or more electrical components related to curing a composite material inside a vacuum chamber at least partially defined by a flexible wall; and an electrical coupler connected to the curing apparatus, the coupler including a first set of one or more electrical contacts electrically connected to the one or more electrical components of the curing apparatus inside the vacuum chamber, the coupler being configured to hermetically extend through a hole in the flexible wall to dispose the first set of one or more electrical contacts in a space outside of the vacuum chamber for electrical interconnection of the one or more electrical components of the curing apparatus inside the vacuum chamber with circuitry disposed in the space outside of the vacuum chamber.

B1. The apparatus of paragraph B0, wherein the one or more electrical components inside the vacuum chamber include a temperature sensing device configured to measure a temperature of the composite material and transmit a signal to the circuitry via the first set of one or more electrical contacts, the signal being indicative of the measured temperature of the composite material.

B2. The apparatus of paragraph B0, wherein the one or more electrical components inside the vacuum chamber include a heating element of a heater mat configured to be powered by the circuitry disposed in the space outside the vacuum chamber via the first set of one or more electrical contacts for applying thermal energy to the composite material to cure the composite material to a cured state.

B3. The apparatus of paragraph B2, wherein the coupler includes mateable first and second connector portions, the first connector portion being mounted on the heater mat, the first connector portion including the first set of one or more electrical contacts, the second connector portion including a second set of corresponding one or more electrical contacts configured for electrical connection to the circuitry, the coupler being configured to electrically interconnect the first set of one or more electrical contacts with the corresponding one or more electrical contacts of the second set and to hermetically clamp a region of the flexible wall surrounding an entire perimeter of the hole when the first and second connector portions are mated.

B4. The apparatus of paragraph B3, wherein the coupler includes a first washer made of a substantially rigid material, and a second washer made of a substantially resilient material that is less rigid than the rigid material, the first connector portion including a base flange connected to the heater mat, the coupler being configured to hermetically clamp the region of the flexible wall against the base flange by the second connector portion pressing the second washer via the first washer against a first surface of the region of the flexible wall to form a hermetic seal between the base flange and a second surface of the region of the flexible wall that is opposite the first surface of the region of the flexible wall.

C0. A method comprising: positioning a curing apparatus on a cure zone of a composite material, the curing apparatus including one or more electrical components electrically connected to a first set of one or more electrical contacts; disposing a vacuum bag film over the curing apparatus opposite the composite material; securing the vacuum bag film to the composite material with an adhesive interface to form a vacuum chamber in which the curing apparatus is disposed; and hermetically extending the first set of one or more electrical contacts through a hole in the vacuum bag film.

C1. The method of paragraph C0, wherein the hermetically extending step is carried out prior to the securing step.

C2. The method of paragraph C0, further comprising substantially evacuating the vacuum chamber to a substantially evacuated state such that the vacuum bag film applies a pressing force against the composite material via the curing apparatus, and maintaining the vacuum chamber in the substantially evacuated state such that an atmospheric pressure inside the vacuum chamber increases by no more than 127 mmHg in a five minute interval of time via one or more of the adhesive interface and the hole.

C3. The method of paragraph C0, where the first set of one or more electrical contacts are included in a first connector portion of a coupler, the method further comprising electrically interconnecting the first set of one or more electrical contacts with a second set of corresponding one or more electrical contacts included in a second connector portion of the coupler that are configured for electrical connection to circuitry disposed outside of the vacuum chamber, the one or more electrical components of the curing apparatus being configured to operate in conjunction with the circuitry by at least one or more of (a) receiving electrical power from the circuitry via electrical interconnection of the first and second sets for applying thermal energy to the composite material, and (b) transmitting to the circuitry via electrical interconnection of the first and second sets a signal indicative of a measure temperature of the composite material for monitoring application of thermal energy to the composite material.

C4. The method of paragraph C3, wherein the steps of hermetically extending and electrically interconnecting are performed at least partially concurrently by the second connector portion mating with the first connector portion to electrically interconnect the second set of corresponding one or more electrical contacts with the first set of one or more electrical contacts and to clamp a region of the vacuum bag film surrounding an entire perimeter of the hole between the first and second connector portions thereby hermetically sealing the hole.

ADVANTAGES, FEATURES, BENEFITS

The different embodiments described herein provide several advantages over known solutions for electrically interconnecting a curing apparatus inside a vacuum chamber at least partially defined by a flexible wall (e.g., a vacuum bag film made of a suitable flexible material) with circuitry disposed outside of the vacuum chamber. For example, the illustrative embodiments described herein permit a first set of one or more electrical contacts associated with one or more electrical components of the curing apparatus to be hermetically extended through a hole in the flexible wall for electrical interconnection with the circuitry. Such embodiments may reduce leaks in the vacuum chamber, simplify bagging and debagging processes, and increase the durability of associated components, particularly as compared to pre-existing apparatuses and methods. However, not all embodiments described herein provide the same advantages or the same degree of advantage.

CONCLUSION

The disclosure set forth above may encompass multiple distinct embodiments with independent utility. Although each of these embodiments has been disclosed in its preferred form(s), the specific details of which as disclosed and illustrated herein are not to be considered in a limiting sense, because numerous variations are possible. The subject matter of the embodiments includes all novel and nonobvious combinations and subcombinations of the various elements, features, functions, and/or properties disclosed herein. The following claims particularly point out certain combinations and subcombinations regarded as novel and nonobvious. Embodiments of other combinations and subcombinations of features, functions, elements, and/or properties may be claimed in applications claiming priority from this or a related application. Such claims, whether directed to a different embodiment or to the same embodiment, and whether broader, narrower, equal, or different in scope to the original claims, also are regarded as included within the subject matter of the embodiments of the present disclosure.

What is claimed is:

1. A method of supplying electricity to an electrical component inside a vacuum chamber, comprising:

positioning an electrical component including a curing apparatus inside a vacuum chamber, the electrical component having a first electrical connector portion,

connecting a second electrical connector portion to the first electrical connector portion through a hole in a flexible wall of the vacuum chamber, the second electrical connector portion being electrically connected to circuitry disposed outside the vacuum chamber, wherein the connecting step includes hermetically clamping the flexible wall of the vacuum chamber between the first and second electrical connector portions.

2. The method of claim **1**, wherein the first electrical connector portion includes a first set of one or more electrical contacts, further comprising:

extending the first set of one or more electrical contacts through the hole in the flexible wall of the vacuum chamber.

3. The method of claim **1**, wherein the curing apparatus includes a heating element.

4. The method of claim **1**, wherein the second connector portion is a male connector portion, and the first connector portion is a female connector portion.

5. The method of claim **1**, wherein the first connector portion is a male connector portion, and the second connector portion is a female connector portion.

6. The method of claim 1, wherein the first electrical connector portion includes a base flange surrounding a barrel, the flexible wall having a clamping region surrounding the entire perimeter of the hole in the flexible wall, the clamping step including pressing the clamping region of the wall against the base flange of the first electrical connector portion.

7. The method of claim 6, further comprising:
hermetically sealing an interior space in the barrel with a potting material.

8. The method of claim 6, wherein the base flange extends from and is connected to the lower portion of the barrel.

9. The method of claim 7, wherein the barrel contains male electrical contacts protruding from the potting material, the second electrical connector portion including female electrical contacts, the clamping step including receiving the male electrical contacts in the female electrical contacts.

10. The method of claim 9, wherein the potting material has a lower thermal conductivity than a material of the male electrical contacts.

11. The method of claim 1, further comprising,
using electricity supplied from the circuitry to generate heat in the electrical component inside the vacuum chamber.

12. The method of claim 1, further comprising:
heating a surface of a composite material inside the vacuum chamber.

13. A method of providing electricity to an interior of a vacuum chamber, comprising:
coupling a first electrical connector portion to a second electrical connector portion through a hole in a flexible wall of a vacuum chamber, including hermetically sealing the chamber by clamping a region of the flexible wall surrounding the entire perimeter of the hole between the first and second electrical connector portions,
wherein the first electrical connector portion is connected to a heating mat applied to a surface of a composite material, further comprising:
curing the composite material by heating the mat inside the hermetically sealed vacuum chamber.

14. The method of claim 13, wherein the second connector portion is a male connector portion, and the first connector portion is a female connector portion.

15. The method of claim 13, wherein the first connector portion is a male connector portion, and the second connector portion is a female connector portion.

16. A method comprising:
positioning a curing apparatus on a cure zone of a composite material, the curing apparatus including one or more electrical components electrically connected to a first set of one or more electrical contacts;
disposing a vacuum bag film over the curing apparatus opposite the composite material;
securing the vacuum bag film to the composite material with an adhesive interface to form a vacuum chamber in which the curing apparatus is disposed; and
hermetically extending the first set of one or more electrical contacts through a hole in the vacuum bag film,
wherein the first set of one or more electrical contacts are included in a first connector portion of a coupler, the method further comprising electrically interconnecting the first set of one or more electrical contacts with a second set of corresponding one or more electrical contacts included in a second connector portion of the coupler that are configured for electrical connection to circuitry disposed outside of the vacuum chamber, the one or more electrical components of the curing apparatus being configured to operate in conjunction with the circuitry by at least one or more of (a) receiving electrical power from the circuitry via electrical interconnection of the first and second sets of electrical contacts for applying thermal energy to the composite material, and (b) transmitting to the circuitry via electrical interconnection of the first and second sets of electrical contacts a signal indicative of a measured temperature of the composite material for monitoring application of thermal energy to the composite material, and
wherein the steps of hermetically extending and electrically interconnecting are performed at least partially concurrently by the second connector portion mating with the first connector portion to electrically interconnect the second set of corresponding one or more electrical contacts with the first set of one or more electrical contacts and to clamp a region of the vacuum bag film surrounding an entire perimeter of the hole between the first and second connector portions thereby hermetically sealing the hole.

17. The method of claim 16, wherein the hermetically extending step is carried out prior to the securing step.

18. The method of claim 16, further comprising substantially evacuating the vacuum chamber to a substantially evacuated state such that the vacuum bag film applies a pressing force against the composite material via the curing apparatus, and maintaining the vacuum chamber in the substantially evacuated state such that an atmospheric pressure inside the vacuum chamber increases by no more than 127 mmHg in a five minute interval of time via one or more of the adhesive interface and the hole.

19. A method of supplying electricity to an electrical component inside a vacuum chamber, comprising:
positioning an electrical component inside a vacuum chamber, the electrical component having a first electrical connector portion,
connecting a second electrical connector portion to the first electrical portion through a hole in a flexible wall of the vacuum chamber, the second electrical connector portion being electrically connected to circuitry disposed outside the vacuum chamber, wherein the connecting step includes hermetically clamping the flexible wall of the vacuum chamber between the first and second electrical connector portions,
wherein the first electrical connector portion includes a base flange surrounding a barrel, the flexible wall having a clamping region surrounding the entire perimeter of the hole in the flexible wall, the clamping step including pressing the clamping region of the wall against the base flange of the first electrical connector portion, and
hermetically sealing an interior space in the barrel with a potting material.

20. A method of supplying electricity to an electrical component inside a vacuum chamber, comprising:
positioning an electrical component inside a vacuum chamber, the electrical component having a first electrical connector portion,
connecting a second electrical connector portion to the first electrical portion through a hole in a flexible wall of the vacuum chamber, the second electrical connector portion being electrically connected to circuitry disposed outside the vacuum chamber, wherein the connecting step includes hermetically clamping the flex-

ible wall of the vacuum chamber between the first and second electrical connector portions, and

heating a surface of a composite material inside the vacuum chamber.

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